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The X Rays

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THE X RAYS.



Foot of boy, age 16, taken with boot on, showing bullet at back of leg. From photograph by the author.

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No. 10.

THE X RAYS

BY

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BRADFORD:—
PERCY LUND & CO., LTD., THE COUNTRY PRESS.
LONDON:—
MEMORIAL HALL, LUDGATE CIRCUS.

1896.

PERCY LUND AND CO., LTD
PRINTERS AND PUBLISHERS



THE COUNTRY PRESS, BRADFORD
AND LONDON

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INTRODUCTORY.

In December, 1895, Professor Röntgen, of the University of Würzburg, published a paper "On a new kind of Rays." That paper, a model of scientific method and completeness, gave an account of experiments on fluorescence and photography, which have excited a popular interest far exceeding that usually accorded to the most brilliant scientific investigations.

The press has teemed with articles on "New Photography." A better title is "Radiography," while for the rays themselves the discoverer's title, *x* rays, is suitable until we have fuller knowledge of them.

We hope to show in this book not only how to use the new *x* rays, but also to give some indication of present theories about them. For whatever it is that Professor Röntgen has discovered, scientists, as a whole, agree that it is some form of vibration. It would therefore seem advisable to indicate how far this discovery is "new," and what was the previous work leading up to it.

For that purpose we shall give a brief account of the vibrations which cause sound, heat, light and chemical effects. We shall point out how our senses of hearing and seeing are limited to particular sets of vibrations, but science has long known other vibrations which we may describe *as sound which cannot be heard* and *light which cannot be seen*. We shall show how to produce and detect this *inaudible sound* and *invisible light*, and indicate how Prof. Röntgen's vibrations are "new" inasmuch as they are probably much more rapid than any previously known, and have remarkable power of penetration.

CHAPTER I.

SOUND. LONGITUDINAL VIBRATIONS.

In describing vibrations we shall proceed from the slowest to the quickest. The slowest we shall deal with are sound vibrations. A steel spring fastened at one end can be made to vibrate by plucking the free end. Its vibrations* are, say, 4 or 5 per second. *It produces no sound.* Shorten the steel spring until the vibrations are 20 per second. *A low musical note is heard.* Shorten the spring again, its vibrations are still more rapid and we hear a note of *higher pitch.* In each case the vibrations produced in the air are similar, but our ears cannot hear vibrations whose rate is slower than about 16 per second. The long, slowly vibrating rod produces vibrations which may be called "inaudible sound"—inaudible because they are too slow.

A Galton's whistle can make very rapid sound vibrations. It is a whistle having a narrow barrel of length adjustable from about an inch to zero; the shorter the barrel the shriller is the whistle; emitting 25,000 vibra-

**Vibration* means the complete *swing-swang* of the moving body or particle.

tions per second the whistle sounds like a sparrow's chirp, at 30,000 it is like a bat's screech, and is inaudible to many persons; above 40,000 it is inaudible to all.

A sensitive flame readily detects these very rapid vibrations. This is a long, thin flame emerging from a narrow, round pipe, the gas pressure being just below the roaring point. In this state air vibrations from a hiss or shrill note cause the flame to flicker and roar; the high notes of the whistle affect it violently, and they continue to do so when inaudible to us. The flame can hear higher notes than we can.

Hence our first point is clear. Our sense of hearing is limited to a particular set of vibrations; there are others of precisely the same nature, but too slow or too quick for our ears. It is quite possible that the hearing of the larger animals extends to a lower range, and practically certain that the cries of many insects are too high for our ears.

A Rough Table of Sound Vibrations.

No. per Second.	
16	Lowest audible.
32	Lowest musical note used.
128	Man's voice in conversation.
256 to 512	Woman's voice in conversation.
2000	High soprano note.
4000	Highest musical note used.
30,000	Bat's cry, inaudible to many.
40,000	Highest audible note.

One note is an octave higher than another when its vibration frequency is double. Thus:—Musical notes extend about 7 octaves; audible notes extend about 11 octaves.

We have still to describe the motion of the air particles conveying the sound.

It is very like the motion along a line of men when the first pushes his neighbour, who passes the push on, and so to the end of the line. A figure makes this clearer.

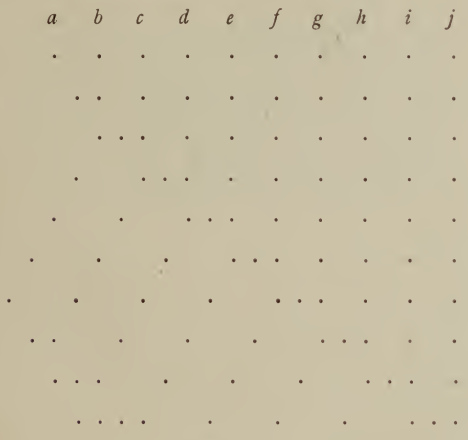


Fig. 1.

The 10 particles, *a*, *b*, *c*, etc., are equidistant until the first *a* receives the blow from the vibrating body. Then *a* moves towards *b* and makes *b* move on, *a* presently returning, and so on along the line.

Our figure represents the particles in new lines each time, but in reality they do

not leave the original line; consequently :—

1. A disturbance travels from left to right.
2. A condensation travels in the same line, a rarefaction the reverse way.
3. Each particle makes a short excursion *to and fro* in the same line.

Such vibrations are *longitudinal*, and the wave motion is a *condensation-rarefaction*.

Fig. 2 illustrates what the air would look like if we could see it whilst transmitting

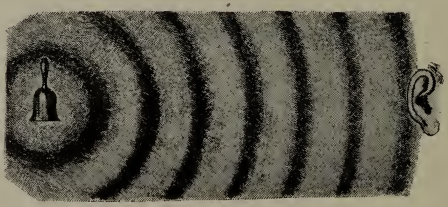


Fig. 2.—Sound waves in air.

these waves from a bell to the ear. The condensations are not stationary, but are all moving on, with velocity about 360 yards per second, and the number that strike the ear per second is the *vibration frequency* which determines the *pitch* of the note.

Prof. Röntgen surmises that his *x* rays are transmitted by extremely rapid longitudinal vibrations.

CHAPTER II.

ETHER VIBRATIONS.

We now leave the slow air vibrations of thousands per second to speak of ether vibrations of millions, billions, and possibly trillions per second.

First, what is *ether ?*

Science has ceased to regard space as empty ; it is filled with a medium called *ether*, which pervades all bodies as well as fills the space between them.

Properties are ascribed to this ether to explain the phenomena of radiation, electricity, magnetism, and the still more subtle difficulty of gravitation. But ether satisfies our needs at present if it merely acts as a "*nominative case to the verb to undulate.*"* And its undulations or vibrations shall be regarded from the simplest mechanical point of view ; *i.e.*, such as would be produced in an elastic solid. Gases can only vibrate *longitudinally*, elastic solids can vibrate both *longitudinally and transversely*.

* Lord Salisbury to the British Association at Oxford.

Hitherto longitudinal ether vibrations had not been recognised: their possibility was so evident that their absence needed explanation. It was supposed that ether was incompressible so that its longitudinal vibrations would travel with infinite velocity, *i.e.*, practically be non-existent. Now Professor Röntgen suggests that his *x* rays are transmitted by longitudinal vibrations—the question is not yet settled—perhaps the

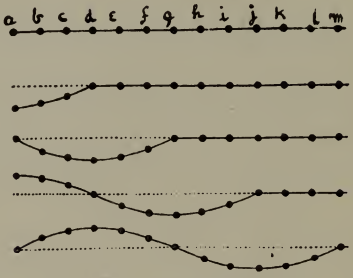


Fig. 3—Longitudinal Vibrations.

majority are in favour of transverse vibrations.

In a transverse vibration the particles move *at right angles* to the line along which the disturbance travels. A figure again makes it clearer.

The disturbance starts by *a* being moved downwards, presently dragging *b* after it, *c* and so on; *a* meantime oscillating upwards past its first position, to be followed by *b*, and so on. The result is:—

1. A disturbance or wave travels from left to right.
2. Each particle makes a short excursion *up and down*.

We are familiar with such waves along ropes, and practically the waves on the *surface* of water are the same. In the ether there is no surface, but the waves spread out in all directions, and we do not consider the particles of ether as necessarily moving *up and down*, but in any direction which is at *right angles* to the direction along which the wave travels.

The distance from crest to crest is called *a wave length*.

Ether waves fall into the following sets:

	Ether vibrations.	Per second.
1.	Hertz, electrical waves..	a few millions.
2.	Heat waves, Infra red	100 billions and upwards.
	Light waves, red.....	400 billions
	Light waves, violet ..	700 billions.
	Actinic waves, ultra violet	up to 2,000 billions.
3.	Röntgen waves	possibly trillions.

All the waves travel at the same rate through the ether, 186,000 miles per second, the short waves as fast as the long ones, they make up for their shortness by vibrating more rapidly.

The first and last sets are produced by electrical means, the middle set probably so.

The first and second sets are certainly transverse, the third set probably so.

Of all these sets only the light waves, extending less than an octave, directly affect the eye—the rest are *invisible light*—in that respect our sense of sight is more limited than our sense of hearing.

We notice large gaps, representing vibrations of which we know nothing. Röntgen has added one set, probably others will soon be added to fill up the gaps. Indeed, since Röntgen's discovery another set between ultra-violet and *x* rays has already been indicated by Mons. Becquerel (see page 61).

CHAPTER III.

HERTZ ELECTRICAL VIBRATIONS.

A Leyden jar consists of a glass jar with inner and outer layers of tinfoil reaching nearly to the top. It is charged by electrical machines, and when discharged gives a bright, loud spark of exceedingly short duration, certainly less than $\frac{1}{100000}$ second.

Nevertheless, even in that short time the discharge is *oscillatory*, several sparks passing backwards and forwards at the rate of some few millions per second. The exact number depends on the size of the jar. With a quart jar it would be about 80,000,000 per second.

With a jar as small as the chemists' molecule the rate would be billions per second, about the same frequency as light vibrations: a result in accordance with the generally accepted theory of light, the electro-magnetic theory of Clerk Maxwell.

These Hertz oscillations resemble the more rapid light oscillations; Hertz first showed they could be radiated to a distance.

The transmitter consists of two plates, A and B, each carrying a thick wire ter-

minated in polished knobs about half an inch apart, which form the "spark gap" for discharging the induction coil connected to the plates.

The receiver may be a simple loop of wire terminated in two bright knobs, whose distance apart is adjusted to the proper amount (perhaps $\frac{1}{10}$ in.)

When properly adjusted a spark passes at the receiver every time one passes at the transmitter. Electrical oscillations have

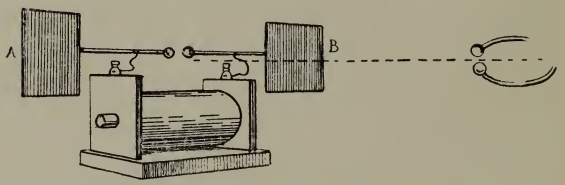


Fig. 4.—Hertz's Radiator and Receiver.

been sent across from the transmitter to the receiver.

These oscillations are *transverse;* they can be reflected, refracted, polarised, and in fact undergo all the modifications that light oscillations can undergo. They differ from light :—

(1) In a much slower rate of vibration.

(2) In producing no effect on the eye.

They are our first example of "invisible light," and we only call them "electrical" because they are produced and detected electrically.

They further differ from light in penetrative power. It is not surprising that a substance which is "opaque" to one set of vibrations, should be "transparent" to another set of slower or quicker vibrations.

In the use of such terms as "opaque" and "transparent" we have been too much influenced by our eyes dealing with light vibrations; for example, the so-called opaque substances—wood, pitch, stone walls, are transparent to the comparatively slow Hertz vibrations.

If these slow vibrations could directly affect photographic plates, they would, to some extent, have anticipated the Röntgen photography by a few years.

CHAPTER IV.

LIGHT.

Of all the interesting facts connected with light we must confine our attention to a few connected with reflection and refraction.

Light proceeds in straight lines in one medium, till it strikes the surface of another

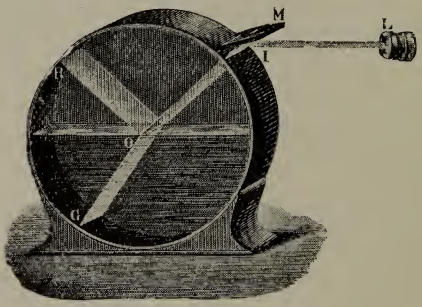


Fig. 5.—Reflection and Refraction of Light.

medium, when it is reflected or refracted into some new direction.

Reflection and refraction, are both shown by the experiment illustrated in fig. 5.

Light from the sun, or a lantern, passes though the slit at L and strikes a mirror at M, it is then reflected into the circular vessel along the direction IO, LI and IO being equally

inclined to the mirror. At O the light strikes the water, and some is reflected along OR, but some enters the water in the direction OG. The path of the light is *broken* at O, so it is said to be *refracted*.

Refraction always takes place at the surface of two media of different densities, the path of the light in the denser medium being more nearly perpendicular to the surface.

With a well polished mirror ninety

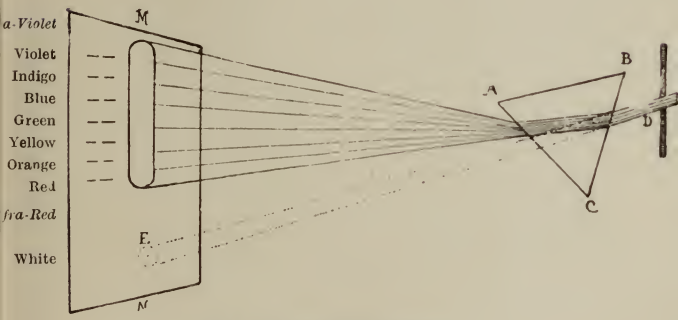


Fig. 6.—Prismatic Spectrum.

per cent. or more of ordinary light may be reflected.

At the very best it is difficult to reflect more than two per cent. of the *x* rays. And the *x* rays have not yet been satisfactorily refracted; they enter and pass through the new medium without changing their direction at all.

But ordinary light is not only *refracted*, it is usually *dispersed* as well. This is best shown

by Newton's experiment when white light is refracted through a prism, A B C (fig. 6).

Not only is the light bent from its original course, DE, but it is spread into a coloured band, which can be received on a screen MN. This series of colours is called the *spectrum*, and is generally said to consist of seven colours—red, orange, yellow, green, blue, indigo and violet: but there is an imperceptible gradation with every intermediate shade. All these colours are due to the same kind of ether vibrations, differing only in wave lengths and vibration frequencies. All travel with the same speed. The shortest and most rapidly vibrating waves are the violet and these are the most refracted.

In the spectrum the position of any band of colour depends on its vibration frequency, the more rapid being the more refracted, and therefore the nearer to the violet.

The following table gives some of the numbers :—

Colours.	Wave Lengths in ins.	Number per second.
Red	0·0000270	450 millions
Yellow	0·0000227	535 millions
Blue	0·0000196	622 millions
Violet	0·0000167	727 millions
Average	0·0000225	540 billions

This set of vibrations is the only set directly perceptible by our eyes. But we can prove that there are :—

1. Vibrations slower than the red whose position in the spectrum is *below* the red, hence their name *infra-red*.
2. Vibrations quicker than the violet whose position is *above* the violet, *ultra-violet*.

1. *The Infra-Red Rays.*—Any form of delicate thermometer placed in the infra-red portion of the spectrum indicates a heating effect, and this effect extends far below the red. In the visible spectrum itself there is a similar heating effect, so that radiant light and radiant heat do not essentially differ, but that radiant heat which is below the red is "dark heat," or "invisible light." This invisible light can be reflected, refracted and "focussed" just like visible light. If it be focussed on a piece of platinum, that piece becomes red-hot, *i.e.*, gives out *visible light*. The platinum has somehow increased the vibration frequency so far as to make the rays visible.

Once again our terms, opaque and transparent, do not apply to the infra-red rays. To these rays black ebonite is more transparent than clear glass. If our eyes were so constructed that we saw with vibrations of frequency below 400 billions, we should use ebonite in our windows in preference to glass.

2. *The Ultra-Violet Rays.*—Referring to fig. 6 we see a region marked ultra-violet. In it there are no visible rays: vibrations are

present but they are too rapid for our sense of sight. But if paper soaked in quinine sulphate be placed at the upper part of the screen, the violet will shine out brighter than before and the region *beyond the violet* will also appear, shining with a bluish light. By some means the quinine can reduce the vibration frequency from invisibility above 700 billions per second, to visibility below that number. This property is called *fluorescence*, as fluor spar exhibits it to a marked degree.

The ultra-violet, "invisible light," quickly affects a photographic plate. If the plate be exposed to the whole spectrum we should find little or no effect at the red end, an increasing effect towards the violet, and most effect in the ultra-violet. Indeed ordinary photography is mainly accomplished by ultra-violet rays. Such rays are called *chemical* or *actinic*. They differ from ordinary light—

(1) In a quicker rate of vibration.

(2) In producing no effect on the eye.

Photography extends the ultra-violet spectrum through a length many times that of the visible spectrum.

Most scientists believe that *x* rays vibrate much faster than the extremest ultra-violet known; yet they are not refracted by a prism but pass straight through to E in fig. 6.

X rays are ultra-ultra-violet in vibration frequency, but have a place in the prismatic spectrum as if infra-infra-red!

CHAPTER V.

ELECTRICAL DISCHARGES THROUGH GASES.

As it is by means of electrical discharges that we get *x* rays, we must now consider those discharges.

Photographs of lightning flashes show tracks like winding rivers, not sharp zig-zags.



Fig. 7.—Electric Sparks.

The small electric sparks between the knobs of our electric machines are similar. (See fig. 7.)

The electric discharge through a rarefied gas, in an exhausted tube is very different. There is no actual spark, but the gas, as a whole becomes luminous, with flickering patches or striæ of light. Fig. 8 shows

roughly the discharge through a Geissler's tube, a sealed tube from which air has been pumped until the residual air has a pressure perhaps less than $\frac{1}{1000}$ part that of ordinary air.

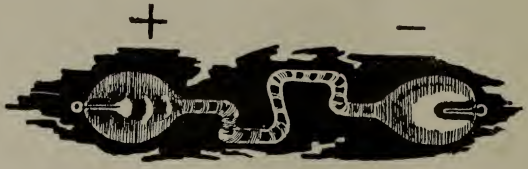


Fig. 8.—Discharge through Geissler's Tube.

The current, from a powerful induction coil, is led to the tube by two platinum wires, fused through the glass, called *electrodes*, respectively *anode* and *kathode*, marked + and —, or A and K.

Anode = road up, where the current enters.

Kathode = road down, where the current leaves.

Note that the luminous striæ extend through nearly the whole tube, but near *the kathode there is always a dark space.* We shall only consider the action in this dark space.



Fig. 9.—The Dark Space.

Improve the vacuum by pumping out more air—the dark space increases. Fig. 9 shows this, the kathode is the middle wire, the anode can be at either end.

Improve the vacuum still more, and the dark space extends throughout the whole tube. Such high vacuum tubes are named after Crookes, who investigated their properties. The residual air may be at a pressure less than one millionth that of the atmosphere.

In Crookes' tubes the electric discharge scarcely illuminates the gas, but illuminates

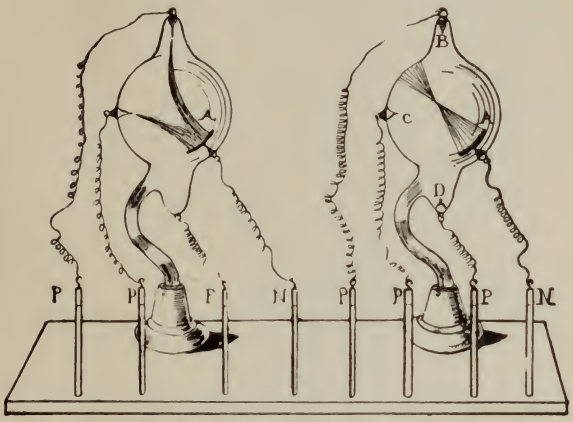


Fig. 10.—Low and High Vacuum.

the glass walls of the tube, which shine with a green light if made of German glass, but with a blue light if made of English lead glass. The *green fluorescent* patches are the starting points of the *x* rays.

Crookes established results, some of which may be summarised thus:—

1. The kathode attracts particles of gas, electrifies them, and then repels them

with great velocity (as much as 120 miles a second).

2. The particles are shot out at right angles to the kathode, and cross the "dark space" in straight lines till stopped by the particles of gas or solid bodies in their path.
3. In a low vacuum tube the free straight path is small; the particles are soon stopped by others, and all of them

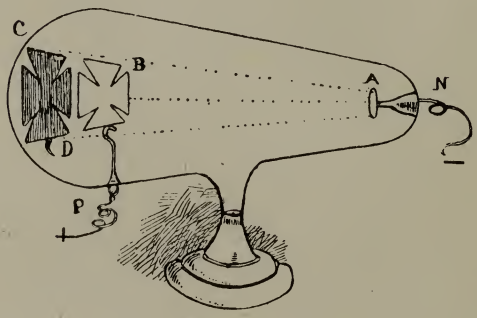


Fig. 11.—Shadow of a Cross.

become luminous; hence the luminous halo round the "dark space" of a Geissler's tube.

4. In a high vacuum tube the particles proceed straight across the whole tube until they bombard the opposite walls, which become hot and luminous, or fluorescent.
5. Any solid body put in their path is also bombarded, and may become hot and fluorescent.

6. A magnet outside the tube deflects the particles inside the tube so that they no longer move in straight lines.

It must be understood that even in high vacuum tubes there are still many million particles of air. These particles, discharged straight from the kathode, form rays, often called "*kathode rays*." Crookes called the



Fig. 12.—Radiant Matter Heating Platinum.

residual gas "radiant matter," and showed its properties by various tubes.

Fig. 10 represents two tubes, respectively *low* and *high* vacuum.

In each the kathode is the disc at the right. The anode may be the top, middle, or side wire.

(*a*) In the low vacuum tube the luminous discharge proceeds from the kathode to whichever wire is the anode: the position of the anode has some effect.

(*b*) In the high vacuum tube the discharge ignores the anode, proceeds straight from the kathode, bombards the glass opposite and makes it fluoresce: the position of the anode has no effect.

Fig. 11 shows the effect of an aluminium cross in the path of the kathode rays.

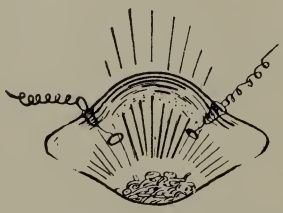


Fig. 13.—Fluorescence of Crystals.

The tube fluoresces, especially at the end, except where it is protected by the cross, which casts a black shadow.

Fig. 12 shows how the kathode rays emitted by the cup-shaped kathode can make a piece of platinum red hot: the particles are "focussed" on the platinum which is at the centre of the cup.

A modification of this tube is the so-called "focus" tube, the best form known for emitting the *x* rays, which seem to start from the central platinum.

Fig. 13 illustrates the fluorescence of a solid body, a diamond or other crystal placed in the path of the rays.

Fig. 14 illustrates actual rotation caused by the particles, and their deflection by a magnet.

The particles shot from the kathode hit the vanes of the "mill wheel," but there is no rotation until the magnet pulls the particles up to the upper vanes, for in the

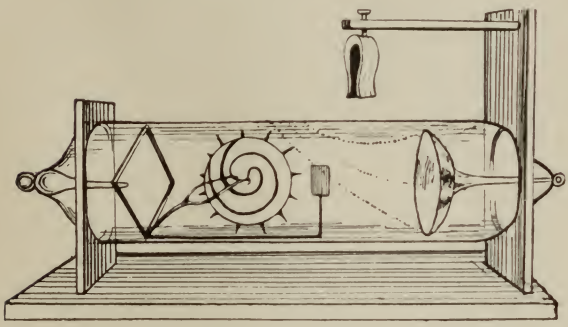


Fig. 14.—Rotation and Deflection.

absence of the magnet the particles hit the upper and lower vanes equally.

We have illustrated the actions inside the tube; is there a continuation of the actions outside the tube? Lenard showed that the kathode rays could pass through a thin "aluminium window" placed opposite the kathode. He thus passed kathode rays from one vacuum tube into another and even for a short distance into air.

But though there must have been *x* rays mingled with these transmitted kathode rays, yet Lenard only recognised kathodic properties.

His transmitted rays were *deflected by magnets* (*x* rays are not), could excite fluorescence, even affect photographic plates, but could only *traverse small distances in air* (*x* rays traverse several yards at least). Lenard led the way for Röntgen's brilliant investigations of actions outside the Crookes' tube.

CHAPTER VI.

DISCOVERY OF *X* RAYS. FLUORESCENT EFFECTS.

We have described what occurs inside the Crookes' tube, enumerating some results known during the last 20 years. It was whilst experimenting on the same lines as Lenard, that Professor Röntgen made his great discovery of the actions outside the tube.

He knew that many salts were capable of fluorescence, amongst others the platinocyanide of barium. He coated paper with this salt to determine the action of a Crookes' tube on it. To shut off the ordinary light emitted by the tube he completely surrounded it with a jacket of thick black cardboard, a material quite impervious to bright sunshine, or the light from the electric arc.

The tube as usual was excited by the discharge from a large induction coil, worked by a few secondary cells. The experiment was done in a darkened room, the paper being held near the enclosed tube. As soon as the current was turned on, the platinocyanide shone with a bright fluorescence,

whichever side of the paper was offered to the tube. The fluorescence was brightest when the paper was near the tube, but it was still visible when the paper was two yards distant.

Something was emitted from the tube, capable of passing through "opaque" black cardboard, and two yards of ordinary air (this distance has been since much increased). It was a "new" light, for it passed through the cardboard; it was not Kathode rays for it passed through air.

If there be interposed between the Crookes' tube and fluorescent screen a playing card, or a thin ebonite sheet, or even a thin aluminium sheet, the fluorescence is scarcely diminished.

A book of a thousand pages or a block of wood a foot thick diminish the brightness, but still the screen shines.

But denser metals, such as a copper coin, cut off so much of the "new" light as to cause "shadows" on the fluorescent screen.

This casting of shadows suggests the idea of "rays" of light travelling in straight lines; and their unknown characteristics were, and are still, fitly indicated by the title *x* rays.

If these *x* rays fall on the eye they produce no visible effect whatever; when they fall on the fluorescent screen they excite

other rays which are visible to the eye. This is quite analogous to the visible fluorescence excited by the invisible ultra violet light falling on quinine (see page 24).

In making the experiment it is evident that the brightest fluorescence is produced when the paper is opposite that portion of the tube on which the Kathode rays fall, a fact which led Röntgen to conclude that this portion is the starting place of the *x* rays.

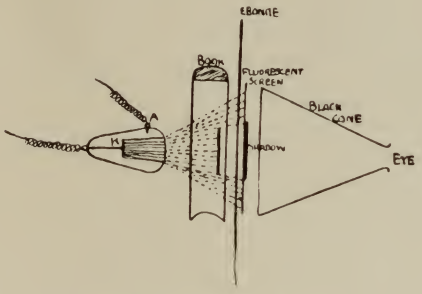


Fig. 15.—Shadows by *x* rays.

In the ordinary Crookes' tube the Kathode rays, projected in straight lines, strike the opposite glass walls and cause green fluorescence (see Chap. V). It is from this patch of green fluorescence the *x* rays start, travelling out thence in straight lines which are not necessarily continuations of the Kathode paths.

A suitable arrangement for casting the shadows is shown in fig. 15. The tube is on the left; the Kathode rays proceed

from K and strike the glass, causing the green fluorescence. The position of the anode A is here immaterial. From the end of the tube the *x* rays proceed in straight lines, dotted in the figure. They pass through the book, but some are stopped by the coin in the book. They then pass through the thin ebonite sheet to the fluorescent screen; this screen shines brightly except where the coin casts its shadow by cutting off the *x* rays. The ebonite is used to shut off the ordinary light emitted by the luminous tube.

The shadow image may be seen in a darkened room, or by looking through a black paper cone, fitting close to the screen so as to cut off all extraneous light.

Professor Salvioni is said to have invented a so-called "cryptoscope" for seeing "hidden objects." He made the black cone and fastened the fluorescent screen, salt inwards, at one end. This cone is pointed at the Crookes' tube, and the substance holding "the hidden object" is placed between the tube and the cone; exactly as in the above figure.

The credit of this "invention" lies entirely in the black cone used to shut out side light. Any photographer looks at the image on the ground glass of his camera, with his head under a dark cloth, or even uses a focussing lens in a tube, without claiming to have made a great invention.

Using either Röntgen's method or Salvioni's modification it is easy to find which bodies transmit and which stop the *x* rays. As the list will be more fully discussed in the photographic section, we shall only mention here that lighter bodies transmit the *x* rays, the heavier ones are more opaque.

But it is well to state at once that there are no substances so opaque that the *x* rays cannot pass through thin sheets of them—there is only relative opacity. To obtain the same amount of absorption we must use thick or thin sheets according to the density, small or great, of the material. Wood, leather, paper, ebonite are very transparent, flesh fairly so, bones less so; the heavier metals are much more opaque.

Consequently dark shadows are cast by metallic objects, even when enclosed in wooden boxes, the nails of the box also cast their shadows. The method has been utilised for detecting the presence of money, or other articles in postal wrappers and cases.

Hence there have arisen such phrases as "seeing the invisible," "looking through a block of wood," etc., which are, however, scarcely justifiable. We do not really *see* the objects, but only their *shadows* cast through the wood and other "transparent" materials.

The hand is a remarkable object, for the flesh casts a faint shadow, the bones a deeper

shadow, metallic objects on or in the hand, a still deeper shadow.

The shadow pictures are precisely similar to the photographic pictures to be presently described. But it is necessary to add that Röntgen saw the shadows of his bones before he photographed them; the credit has been wrongly assigned to Salvioni and others.

We may add that, with better tubes and screens, shadows of all the joints, backbone, head, etc., have been cast and examined; and *x* rays have been transmitted through the whole body, or even through the bodies of two men.

One can make a good fluorescent screen thus: Grind pure barium platino-cyanide to finest powder; mix it with some varnish, such as magilp. Spread it *uniformly* on a glass plate to a thickness of one-tenth of an inch; cover the varnish with black paper or ebonite, it need not be dry first. The ebonite should be the thinnest sheet procurable.

The observer must place the screen between himself and the Crookes' tube; the ebonite being nearest to the tube and the glass nearest to the observer. The objects are placed between the tube and ebonite, as near the latter as possible.

Other materials have been suggested, such as potassium platino-cyanide and calcium tungstate. The former is said to

give better results, but must be kept moist ; the latter is Edison's "invention" and must be "properly crystallised" (methods not yet described and otherwise the results seem no better than with the platino-cyanides).

CHAPTER VII.

PHOTOGRAPHIC METHODS.

Professor Röntgen is said to have discovered the photographic effects of *x* rays accidentally, but even so it was the sort of accident that only a man of genius would turn to good account; in any case the analogies between ultra-violet rays and *x* rays would have soon led to experiments on photographic plates.

For photographic purposes the fluorescent screen must be replaced by a box containing a photographic plate.

Fig. 16 shows a suitable arrangement. The tube has its axis vertical, the kathode rays are shot downwards from K, rendering the glass fluorescent at G G. From G G the *x* rays diverge outwards as in the dotted lines; some of them are stopped by the object. They pass through the lid of the box, and cast the shadow of the object on the plate. As the box is impervious to ordinary light, the operation need not be conducted in the dark.

The actinic or chemical intensity of the *x* rays is comparatively feeble, so

that the "exposure" needs to be somewhat prolonged.

The time of course depends on the distance between the source of the rays and the plate—for the intensity of "illumination" follows the usual rule, viz., it is inversely as the square of the distance; doubling the distance quadruples the exposure. At a distance of six inches, exposures were often,

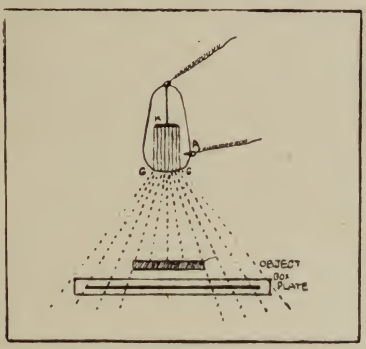


Fig. 16.—Photography by x rays.

in the earlier experiments, as much as one or even two hours. But with better tubes, particularly the focus tube (see page 46), the exposures have been much reduced.

With an induction coil capable of giving a three-inch spark, a focus tube, and a rapid plate, distant, as before, six inches, the exposure for simple metallic objects may be only thirty seconds; for a hand perhaps one or two minutes, for an arm or leg increased

periods according as the *x* rays have to penetrate increased thickness.

As to plates, any good fast plate is suitable; perhaps thickness of emulsion is even more important than speed, for it is obvious that the *x* rays pass through both the emulsion and plate. The *x* rays have been made to pass through a packet of 200 bromide papers, impressing the same image on the lot simultaneously.

The photographic effects are practically the same whether the emulsion be spread on glass, films, ferrotype, or paper. Professor Röntgen suggested that the photographic effects might be caused either directly or indirectly.

1. Directly: *i.e.*, the effect of the *x* rays on the silver salts is similar to that of light waves.
2. Indirectly: *i.e.*, the *x* rays cause fluorescence in the glass, or other support of the film, and this luminosity causes the usual photographic effect.

It is evident that the fluorescence of the glass plate is unimportant, for the same effect is produced on ferrotype, which does not fluoresce.

Nevertheless the effect may still be indirect, being caused by the fluorescence of the gelatine, collodion, or the silver salts.

It naturally occurred to many of us that the photographic effect might be hastened by

placing a fluorescent screen in contact with the emulsion, or by mixing fluorescent materials with the emulsion.

The first method, in several hands, reduced the exposure to one-fifth the time, but gave less satisfactory images. For there was a spreading of the light, a halation, as well as a granular appearance due to the particles of the fluorescent salt. If short exposures are a great desideratum the screen can be recommended. A convenient method, suitable for films is as follows:—Place the film, sensitive side downwards, on the fluorescent screen: the *x* rays pass through the film and emulsion to the screen. The method is less suitable for glass plates owing to the much greater "opacity" of glass.

The second method gives better results and undoubtedly hastens the exposures.

In every case the development offers no special characteristics; as a rule a rather slow development seems most suitable; and as the whole thickness of the emulsion is affected, development may be carried rather further than usual.

It is sufficiently obvious that all *x* ray photography is only the photographing of shadows, though there may be, of course, "half-tone" in the varying intensities of shadows.

It is desirable that the shadow images should be as sharp as possible. How are we to secure this?

Fig. 17 shows the shadow cast by the ball K when the source of light is a single point S.

A screen put at any distance behind K will receive a perfectly sharp shadow image.

Fig. 18 shows the shadow cast by the ball B when the source of light is another larger ball A.

In the more deeply shaded portion the light from the luminous body is completely shut off: this portion is the *umbra*, or complete shadow. In the other portions there is light



Fig. 17.—Shadow cast by luminous point.

from some part, but not from the whole of the luminous body: these portions form the *penumbra* or part shadow. A screen placed at MN receives a blurred shadow, darkest in the middle, fading off towards the edges. The shadow is sharpest when the screen is as close as possible to the opaque object.

If A were moved further from B, the umbra and penumbra would more nearly coincide, and the shadow be sharper.

For sharp shadows it is, then, necessary:—

(1) To use a small source of illumination.
(2) To put the screen receiving the shadow close to the opaque object.
(3) To put the luminous body as far away as possible.

In radiography, No. 1 can be effected by the so-called focus tube (fig. 19).

The concave kathode "focusses" its kathode rays on the anode A, placed at the centre of the tube. This anode is a small plate of platinum inclined at 45° to the axis

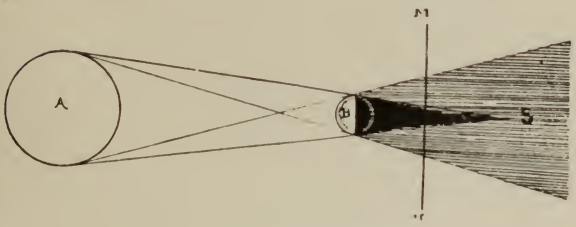


Fig. 18.—Umbra and Penumbra.

of the tube, this plate reflects the kathode rays downwards to the glass, whence they diverge as *x* rays.

When the induction coil is properly connected, all the glass in front of the anode shines with bright green fluorescence, behind the anode it is less luminous. The concentration of the rays on the anode, and their reflection thence, seem to lead to a greatly increased efficiency in producing *x* rays. These *x* rays diverge as if they had started

from the platinum anode A, and the "source of illumination" being small the shadows are consequently sharp. With other Crookes' tubes the origin of the *x* rays has been stated to be that part of the glass bombarded by the kathode rays; in this tube it appears to be the bombarded piece of platinum.

In every case it is probable that *x* rays originate from all solid bodies bombarded by kathode rays. Some experimenters have therefore suggested that they should be called anode rays: but this is very unsuitable, as

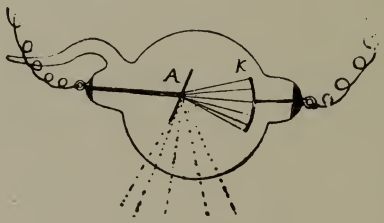


Fig. 19.—The Focus Tube.

the fluorescent particles of glass are not necessarily anodes: *anti-kathodic* rays would be better as indicating their origin from the *anti-kathode*, the part opposite to the kathode.

The second desideratum for sharp shadows can be secured by having the opaque object and the photographic plate separated by as thin a substance as convenient. The plate is often put in a black paper envelope on which the object, or hand, is laid. I have also used a box with a light-tight lid of thinnest

sheet ebonite which lies in contact with the enclosed plate, the object being laid on the ebonite.

The third desideratum is only limited by our desire to have short exposures: the further we put the tube away, the longer the exposure, at twice the distance, four times the exposure; thrice the distance, nine times the exposure, and so on.

For most objects eight to eighteen inches will be considered convenient.

We need not enter into details on the electrical appliances. Any good induction coil will do the work; one giving not less than a two-inch spark in air is desirable. It can be worked by about six primary cells, Grove's, Bunsen's, or Bi-chromate. But for frequent use, three or four portable secondary cells are far more convenient: they can usually be recharged at a small rate at any place where dynamos and electric lighting are in use. If a current from the main is obtainable suitable resistances must be inserted, for the primary of an induction coil is only intended to carry currents of a few ampères.

CHAPTER VIII.

RADIOGRAPHS.

Having described the methods of radiography we add a few examples.

Fig. 20 is the radiograph of the contents of a closed wooden box.

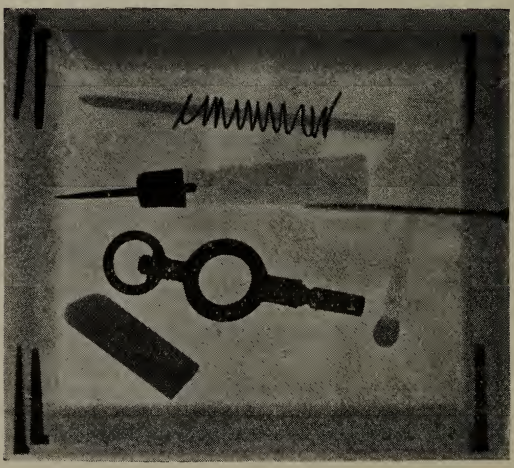


Fig. 20.—Contents of a Box.

The objects were—a watch key, a piece of glass, a wax vesta, a pencil with platinum wire wrapped round it, a small bradawl. The metallic objects are most opaque, and the

glass (probably flint glass) is also surprisingly opaque; the wax again is much more transparent than the phosphorous head of the match, and the lead is visible inside the pencil. The positions and lengths of the nails in the wood-work are very clearly seen; the pin was hidden in the wooden lid.

Fig. 21 is the radiograph of five layers of tinfoil, made by piling up the large circle, star shape, small circle, square, and lozenge-shaped pieces.



Fig. 21.—Layers of Tin-foil.

The increasing opacity, with increasing thickness is very obvious. It will be observed that the single layer is fairly transparent.

We might here remind the reader that gold leaf, as thin as the hundred-thousandth of an inch, is transparent to ordinary light, or at any rate to green light: for such a piece of gold appears green when looked through.

But the transparency of metals for *x* rays is far in advance of this: for *x* rays have been transmitted through an inch or more of aluminium, and even faintly through a sovereign, though gold quickly absorbs these rays.

We might also add that just as a gold leaf will select green light for transmission and not the whole of the white light, so it is probable that there is selective absorption in

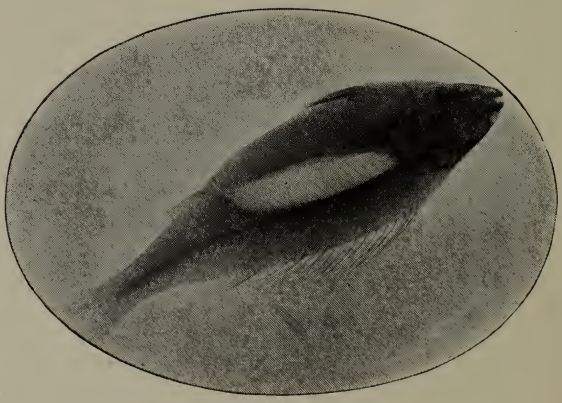


Fig 22 —A Perch.

the case of *x* rays, for it is improbable that they are all of one wave length. It is hoped by this selective method to get *x* rays which will more clearly distinguish the various tissues of the body, and not only indicate bones as distinct from flesh.

Fig 22 is the radiograph of a perch. The skeleton and plates of the skull

come out well; the light region in the middle is the inflated air-bladder.

Fig. 23 shows the bones of a child's hand and forearm.

The cartilage at the joints is practically as transparent as the flesh, hence the apparent intervals between the bones. The child was only five years old, and the photograph beau-



Fig. 23.—Hand of Child.

tifully illustrates the incomplete ossification: the heads and bases of the phalanges in the fingers are not yet united to the shafts, and the wrist mainly consists of cartilaginous material rather than of bones.

Fig. 24 shows the contrast with the bones of an adult.

This radiograph was obtained from the hand of a mummy, probably a lady's hand, certainly over 3,000 years old. The thumb and little finger have sustained damage, but the bones are still astonishingly clear. The bones have retained their original character-



Fig. 24.—Hand of Mummy.

istics, though the flesh is black and shrivelled. Parts of the cloth binding are visible between the fingers. The whole represents a curious intermingling of the science of ancient Egypt and of modern times.

CHAPTER IX.

USES OF RADIOGRAPHY.

It would be quite premature to attempt a complete list of the uses of radiography—in many respects the subject is only passing through its initial trials. We shall therefore give only a few of the results obtained.

First we give one of Prof. Röntgen's tables indicating the varying opacity of metals. The sheets were made of such thickness that they cast equally dense shadows; for comparison the platinum is said to be of unit thickness, the aluminium of unit opacity.

	Thickness.	Opacity.	Density.
Platinum	1 ..	200 ..	21·5
Lead	3 ..	66·6 ..	11·3
Zinc	6 ..	33·3 ..	7·1
Aluminium	200 ..	1 ..	2·6

Obviously opacity depends on density, though no definite law has been discovered. Opacity does not vary directly as density, for platinum is 200 times as opaque as aluminium, though only a little more than 8 times as dense.

The salts and compounds of the metals also, as a rule, increase in density and opacity

together; their solutions behave similarly. The powdered material seems to have the same opacity as a corresponding thickness of the solid material. Powders, even of transparent materials, are very opaque to ordinary light, owing to the great amount of light which is *scattered* by reflection at the innumerable surfaces of the particles. Obviously *x* rays are not freely scattered—in fact, they are reflected to a very small extent, even by powders.

For the same reason the opacity of a material does not depend on the roughness of its surface.

Several experimenters consider that opacity depends on molecular weight rather than density. For example, mercury is less opaque than lead, their molecular weights being as 200 to 206, their densities as 13·4 to 11·3. However, there is some hesitation in accepting these comparisons of densities, so long as the measurements depend on estimation of the depths of shadows cast by a variable source like a Crookes' tube.

It may however be safely assumed that the denser substances are more opaque, and as of course weight depends on density there seems some possible connection between *x* rays and the force of gravity, a connection which may perhaps lead to a solution of the great physical problem, gravitational attraction.

The *x* rays do not directly affect the eyes, possibly they do not reach the retina, for the lens and humours of the eye, though not very dense, are found to be very opaque.

The bones owe their greater opacity as compared with flesh to the presence of mineral matter, mainly calcium phosphate. If this be dissolved out by acids the remaining gelatinous substance is about as transparent as flesh. Metals and glass, particularly English glass containing lead, are more opaque than bones.

The medical profession will decide for itself how far radiography may be of service. For the detection of foreign bodies, such as needles, glass and even swallowed coins, its use is obvious and now frequent. Many photographs of bone have been taken to distinguish dislocation from fracture at a much swollen joint, ankylosed joints, tubercular disease of bone, good or bad union after fracture, the exact nature of abnormalities such as a supernumerary phalanx. Bandages and splints are generally so transparent that they need not be removed except to improve the sharpness of the negative.

The use of *x* rays for the softer tissues has been limited, but photographs have been taken of the cardiac region, of the neck showing larynx and trachea, and even with some success of the abdominal viscera. In particular, diagnosis has been confirmed and

assisted in cases of gall stones and renal calculi.

The surgical uses will extend as tubes improve, and especially when the heterogeneous *x* rays have been so sifted as to find those which will more clearly distinguish the softer tissues.

More attention has been devoted to finding surgical uses than for other purposes. We have already mentioned how *x* rays, by the fluorescent screen, as well as by photography, can discover coins and other illicit matter in postal cases. They might be used on dynamite bombs or dangerous parcels; they distinguish diamonds from the much more opaque paste. They show the character of a welding when the metal is thin enough. The engineer hopes for the time when cavities and flaws in much thicker pieces of metal will be made apparent.

Of the many other uses mentioned in print the reader can doubtless discriminate between the genuine and the grossly exaggerated accounts.

CHAPTER X.

THE NATURE OF *X* RAYS.

Most of the work on radiography has been in confirmation and extension of Prof. Röntgen's original results. A new discovery was made by Prof. J. J. Thomson in England, and other workers on the continent, who tried the effect of *x* rays on electrified bodies.

Prof. Thomson enclosed his Crookes' tube and induction coil in a metal-lined case, so as to completely shut in all direct electrostatic action. The *x* rays from the tube passed out of the box through an aluminium window, and then fell on the electrified body, which was in connection with a gold leaf electroscope or other instrument for indicating electric charges.

As soon as the *x* rays fall on the body they begin to discharge it, as shown by the falling together of the previously divergent gold leaves. The discharge is effected whether the original charge be positive or negative—even if the electrified body be buried in insulating material like wax.

The experiment may be worked by the apparatus shown in fig. 25.

The large metal sheet screens off direct electric action ; the *x* rays pass through the aluminium window, and fall on the copper plate buried in wax. The copper plate is connected by a wire with the charged gold leaf electroscope : the diverging leaves soon fall when the *x* rays reach the copper plate.

The wax is no longer able to insulate the electric charge, which consequently passes away. *All insulators through which x rays are passing become, for the time being, conductors of electricity.*

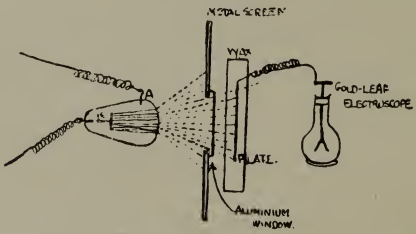


Fig. 25.—Electrified Plate Discharged by *x* Rays.

This method has been used by Prof. Thomson for accurate quantitative measurements, the time required for complete discharge being a measure of the intensity of the *x* rays.

It was previously known that ultra-violet light had a similar power of discharging electrified bodies, but only if the original charge be negative.

Indeed, the analogies between *x* rays and light have now become so close, that the only

theory which gains much credence is that which regards *x* rays as due to *transverse* ether vibrations, similar to, but much more rapid than, ordinary light vibrations.

It is of interest to see why Prof. Röntgen was originally led to consider them as *longitudinal* vibrations. His argument was based on the behaviour of crystals towards *x* rays.

Light vibrations, passing through crystals, undergo various modifications on account of their transverseness. For example, Iceland spar breaks an ordinary beam of light into two; the light is *doubly refracted* into two slightly divergent directions, and double images are produced.

But *x* rays pass through this crystal without double refraction, producing only one image, as they would do if due to longitudinal vibrations. But it is unsafe to conclude that they are necessarily longitudinal, for they are not refracted at all, but pass straight through without deviation.

There is a natural desire to explain the new phenomenon without attributing new and unusual properties to the ether; and scientists do not see the necessity for longitudinal ether vibrations, if *x* rays can be accounted for by transverse ether vibrations.

Now the formulæ deduced by mathematicians indicate that the refractive indices for all substances transmitting transverse vibrations approach unity, when the wave lengths

are so small as to be comparable with the size of the molecules. If the waves are sufficiently small they will be neither singly nor doubly refracted, but pass straight through any substance, just as *x* waves do.

Again, transverse light vibrations which pass through a tourmaline crystal are *polarised—i.e.*, the vibrations are all made perpendicular to a particular plane dependent on the crystal. Such polarised light can pass through a second tourmaline placed "*parallel*" —*i.e.*, in a position similar to the first; but cannot pass if the second tourmaline be "*crossed*"—*i.e.*, turned through an angle of 90° compared to the first.

Longitudinal vibrations cannot be polarised.

Can *x* rays be polarised?

Prince Galitzine and M. de Karnojitsky have got more *x* rays transmitted through *parallel* than through *crossed* tourmalines. If this is confirmed, the polarisation, and therefore transverseness of *x* rays are undoubtedly established. But unfortunately this experiment is hardly yet decisive, for other experimenters have not obtained the same result, which may depend to some extent on the exact composition of the crystals.

Though Prof. Röntgen got no good evidence of reflection, other experimenters have. They have placed the photographic plate at the extremity of a tube made of thick

metal, impermeable to *x* rays. The *x* rays can only enter the tube at the open end where a polished metallic reflector is placed. In this way some small percentage of the *x* rays has been reflected down the tube so as to produce the usual photographic effect. The percentage is never very high, perhaps not over two per cent.; it is greatest when the incident and reflected radiation are nearly parallel to the surface.

The difficulty in reflection is due to the surface being insufficiently smooth. The reflecting surface must have its roughness, its hills and valleys, small in comparison with the wave length of the reflected radiation. Rough rocks reflect sound, polished mirrors reflect light, a still higher degree of smoothness is probably required for the minute *x* waves.

Recently, another remarkable connection between light and *x* rays has been discovered by Mons. Becquerel. He has, in fact, found a missing link between ultra-violet light and *x* rays, filling up one of the gaps in the series of ether vibrations.

When sunlight falls on the double sulphate of potassium and uranium the salt *fluoresces*. On removal from sunlight the *visible fluorescence* lasts for an exceedingly short time, not more than $\frac{1}{100}$ of a second. But an *invisible fluorescence*, if one may use the term, continues for many hours and days afterwards.

In later experiments, Mons. Becquerel used the metal uranium, obtaining better results than with its salts.

These *fluorescent radiations* have some of the properties of *x* rays, and some of the properties of ordinary light. They can penetrate "opaque" substances, such as black paper, thin aluminium and copper, and produce the now familiar shadow photographs. They can discharge electrified bodies, whether the charge be positive or negative. In all these respects, however, their effects are much feebler than those produced by *x* rays.

The *fluorescent* rays differ from *x* rays inasmuch as they can be reflected and polarised like ordinary light. They are, therefore, certainly transverse vibrations, and add to our belief that Röntgen vibrations are also transverse. They are intermediate between light and *x* rays, and would appear in the gap between ultra-violet and Röntgen vibrations in the table given on page 15.

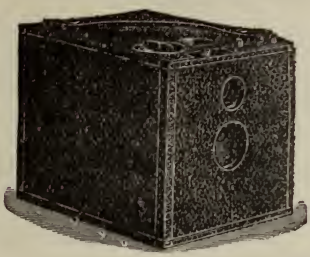
This table is then a record of some of the work on ether produced during the present century by scientists of the three great European nations, the English, French and German. A friendly rivalry during the next century will doubtless extend this work, with results, which, in their practical applications, will be beneficial to all mankind.

Scientific discoveries are always unfolding the wonders of the universe, and in no

direction is the work more hopeful than in this connection between electricity and ether vibrations. Even before Prof. Röntgen's discovery, Sir Douglas Galton could make use of such words as these:—"It is only within the last few years that we have begun to realise the close connection between electricity and those vibrations which cause heat and light, and which seem to pervade all space—vibrations which may be termed the voice of the Creator calling to each atom and to each cell of protoplasm to fall into its ordained position, each as it were a musical note in the harmonious symphony which we call the Universe."

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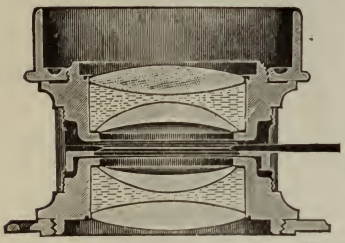
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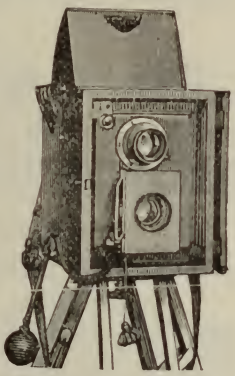
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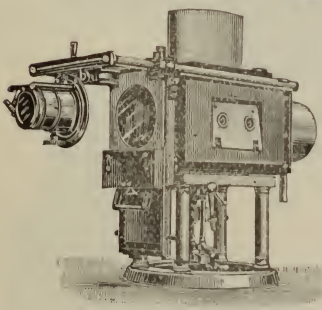
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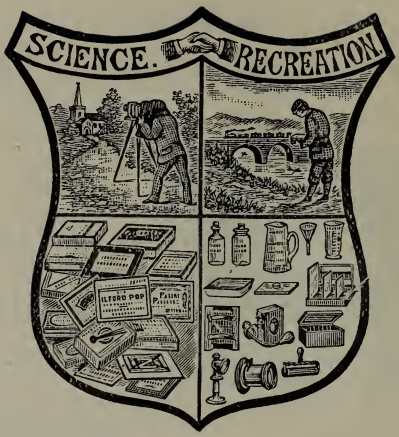
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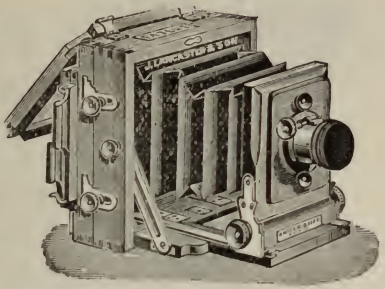
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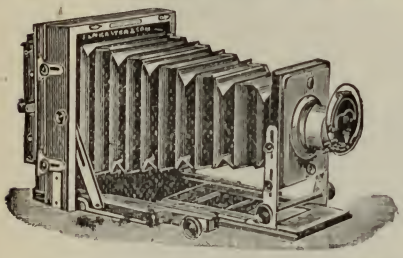
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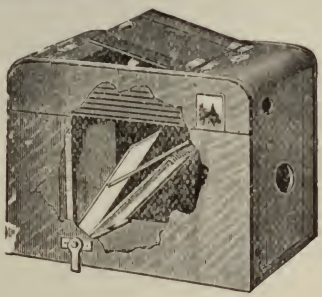
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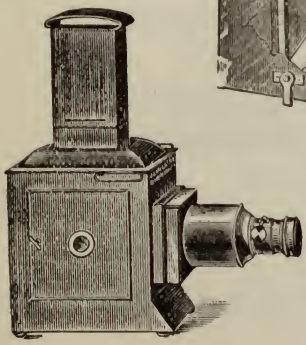
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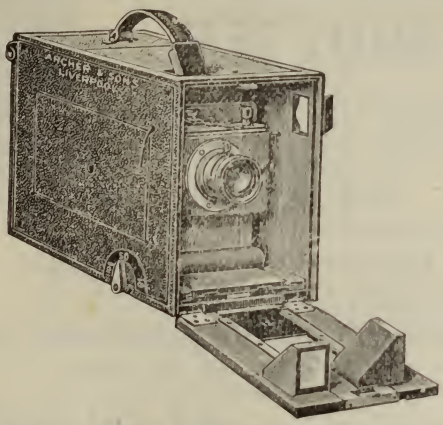
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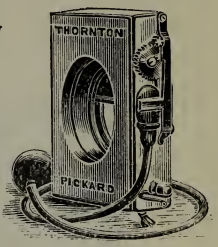
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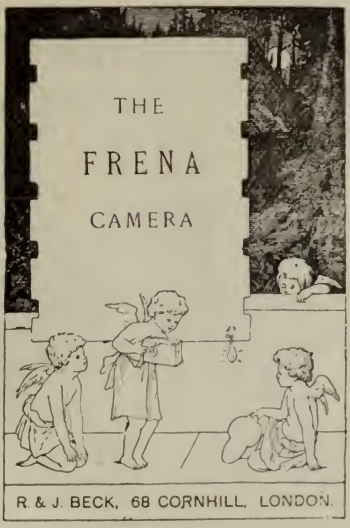


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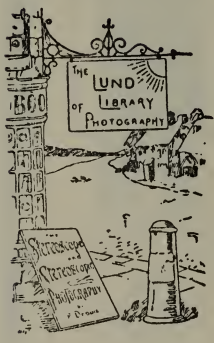
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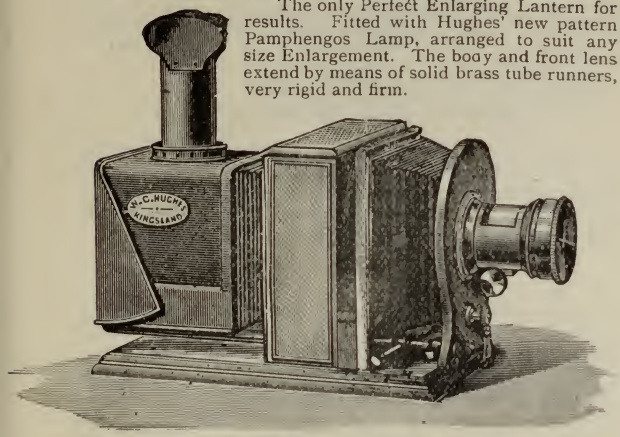
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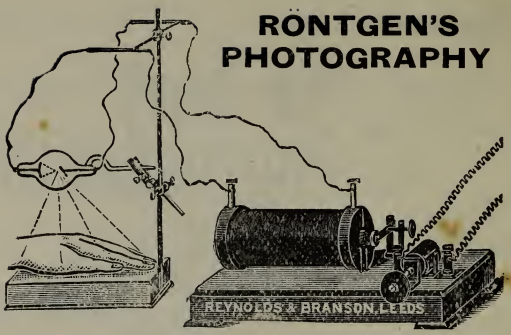


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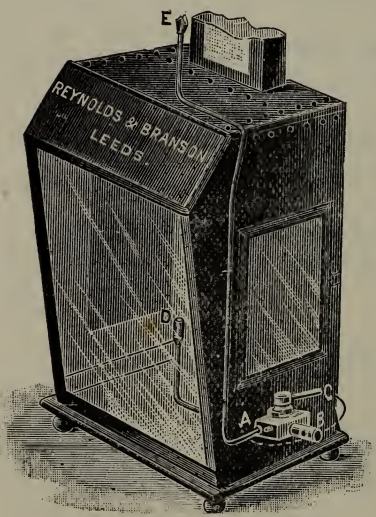


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